Cervical Carotid Imaging With a Continuous-Wave Doppler Flowmeter

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Abstract:
A noninvasive technique for carotid arteriography using an ultrasonic directional Doppler flowmeter to image the carotid bifurcations is described. The technique uses a position sensing arm to hold the sharply focusing probe and translates the position of arterial flow onto an image storage screen. By multiple manual sweeps across the cervical carotids, a two-dimensional projection of the locus of arterial flow is developed. The probe beam is then applied through the eyelids to assess the posterior orbital ophthalmic flow. The adequacy of the internal carotid circulation and the presence of stenosis and calcified plaques are determined. Experience with the first 60 patients surveyed using the Doppler technique demonstrated a high degree of accuracy and reproducibility. The ultrasonic angiography provided local flow and velocity information that x-ray angiography did not. X-ray angiography is frequently indicated by the ultrasonic findings when risks of x-ray angiography might not otherwise be taken. The technique was found especially sensitive in detecting calcified atherosclerotic plaques and may be used in screening for the stroke-prone patient and following arterial lesions over extended periods of time.

Additional Key Words  ultrasonic directional flowmeter  focusing probe  stroke prevention

Introduction
This report presents our experience with a new technique for imaging the carotid circulations. The technique has been made possible by the use of a continuous-wave Doppler ultrasonic directional flowmeter. The unique capability of the Doppler angiographical procedure is to clearly image internal carotid flow and separate it from external flow, showing both direction and velocity. We have used it to localize areas of stenosis and calcified atherosclerotic plaques. Its diagnostic capability is greatly enhanced by determination of the direction of flow in the retrobulbar ophthalmic arteries. The procedure is noninvasive and offers an alternative to x-ray angiography which can be dangerous and is more costly.

The first use of a Doppler ultrasonic directional flowmeter in application to carotids was by Miyazaki and Kato. They compared left to right carotid arteries in patients with hemiplegia. Goldberg suggested listening with the transducer on the eyelid over the suspected side to determine the presence of internal carotid disease and collateral from the contralateral carotid by compressing first the contralateral and then the ipsilateral common carotid arteries. Brinker et al. detected stenosis by direct listening over the cervical carotids, and Maroon et al., using the flowmeter of Stegall et al., found the ophthalmic flow signal to be more sensitive than ophthalmodynamometry. Taniguchi correlated effects of age, blood pressure and ophthalmoscopy findings with the spectral analysis of the ophthalmic flow signal. Müller, using the ultrasonic Doppler directional flowmeter of Pourcelot, demonstrated reversal of flow in the terminal branches of the ophthalmic artery in the medial canthus with occlusion of the internal carotid in 31 of 37 patients. In only
one patient was the signal completely normal, and this was because of an atypical origin of the ophthalmic artery. Planiol et al.\textsuperscript{10} combined the use of facial thermography with directional Doppler examination of the ophthalmic arteries as well as the internal and external carotids to describe typical normal wave forms. Brisman et al.,\textsuperscript{11} as well as many others, however, have found it very difficult to separate the internal from the external carotid flow with a handheld Doppler probe.

Doppler flow probes were linked to position sensing arms by Reid and Spencer,\textsuperscript{12} Gould et al.,\textsuperscript{13} and Fish\textsuperscript{14} to produce ultrasonic angiograms of subcutaneous arteries. This linkage allows an image to build up which can localize and separate between subcutaneous blood vessels. The usefulness of this in non-invasive carotid circulation evaluation, together with directional flow metering in the retro-orbital ophthalmic artery, is the subject of this report. The present system was invented, built, developed and put into clinical application by the authors.\textsuperscript{15-17} The use and problems encountered will be discussed.

**Methods**

**General Description**

The equipment used (fig. 1) consists of a sharply focusing Doppler ultrasonic pencil probe connected to a mechanical scanning arm and of continuous-wave directional Doppler circuitry. The probe's position is electrically sensed by conventional spot-positioning circuitry which positions the spot on an image storage oscilloscope. A signal processing unit receives the directional Doppler flowmeter signal from the electronics package. This unit intensifies the Z axis of the image storage oscilloscope only for a given direction of flow, eliminating venous flow signals superimposing the arterial signal. A loudspeaker makes it possible to hear the Doppler shifted audio signals. A monitor oscilloscope and strip chart printout show and record the analogue directional blood flow signals. A further advantage of the directional sensitive circuit is the rejection of many artifactual noise signals which accompany probe motion in all Doppler systems. By repeated passes of the probe over the vessels, we build up a two-dimensional picture of the blood flow channels. The image formed is similar to the morphological display of the x-ray angiography but represents a functional projection of local blood flow velocities.

![Schematic layout of Doppler ultrasonic angiographical system.](http://stroke.ahajournals.org/DownloadedFrom/0/00.png)
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Several types of probe position translators are possible. The one in current use is a telescoping rho-theta arm mounted on a rotating post and gimbal (fig. 1). The telescoping motion of the arm is linked to the rho potentiometer, and the rotating post to the theta potentiometer. The arm mount is fixed by means of a rigid support to the patient's table. It extends down from above the head to allow the operator to hold the probe against either side of the neck. A horizontal adjustment allows positioning of the arm for either right or left cervical scanning.

POSITIONING OF MAPPING EQUIPMENT

The subject is placed supine on a firm table with the head motion restricted by two lateral pads. The image storage oscilloscope is at the head of the table so that its writing surface lies parallel to the plane of the positioning arm's coordinates. Positioning of the arm up or down, i.e., anterior-posterior, is sensed on the vertical ordinate of the oscilloscope. Positioning in the head-foot direction is sensed on the horizontal coordinate. Movement in the lateral direction is allowed by gimbals but is not sensed and not translated to the storage screen. This lateral freedom provides for variations in the contour of the neck.

The Doppler focusing probe is mounted on the arm so that its beam is projected parallel to the table top to provide a lateral view of the carotid blood vessels. In order to preserve a 1:1 ratio of the vessel diameter to the anterior-posterior distance of arm motion, it is necessary that the Doppler probe always be mounted with its beam perpendicular to the arm axis. The probe's sound beam is directed slightly headward at an angle of 60° with the projection plane in order to obtain a significant Doppler shift signal from the flowing blood.

OPHTHALMIC FLOW TECHNIQUE

Ophthalmic arterial flow is detected in the posterior orbital fossa by placing the 3-cm to 4-cm focus probe over the closed lid (fig. 2). The probe directs the beam through the eyeglobe into the posterior aspect of the orbital fossa where the ophthalmic artery and its branches are coursing in a posterior to anterior direction. By searching flashlight fashion the operator listens to the Doppler shifted audio signal and observes the analogue flow tracing to determine both the direction of flow and the arterial or venous character of the sounds.

Several venous and arterial signals may be detected in different regions of each posterior orbital fossa. Since the direction of the posterior orbital arterial flow is of great significance in judging the adequacy of the internal carotid flow and pressure, care must be taken to assure that a pulsatile venous signal flowing in its normal posterior direction is not interpreted as reversed flow in the arterial channel. The flow direction is easily determined by the Doppler flowmeter. Normal posterior orbital arterial flow signals have a pulsatile sound as well as an analogue contour similar to the carotid arterial signals. The difference is that the arterial flow is directed toward the probe. Orbital venous signals, directed away from the probe, are occasionally pulsatile, but they have a lower frequency range and also display a characteristic analogue contour different from that of the arterial signals. When only a posterior flowing signal is discerned, a compression and release test is especially indicated. A slight compression of the globe with the probe will obstruct the venous flow and its audio posterior moving venous signal. Release of the pressure will cause an immediate large surge of venous flow similar to what one hears over superficial veins of the extremities.

VERTEBRAL FLOW TECHNIQUE

Frequently, the vertebral arterial flow can be detected by placing the probe at the base of the skull at the posterior-inferior margin of the mastoid process, thus directing the beam medially and in a slightly anterior direction. By tilting the patient's head strongly forward and toward the opposite side, the vertebral artery is examined at the point where it is coursing in a medial direction before it enters the foramen magnum. Considerable practice is necessary to master this technique, and even with the best efforts normal subjects at times do not display a vertebral artery signal. The effort is worthwhile, however, to complete the four-vessel study of cerebral circulation.

STUDY MATERIAL

Twenty normal subjects from among healthy hospital volunteers were studied during initial tests. Sixty patients were mapped with the test from February through June, 1973. A written report of carotid Doppler survey findings was placed in the hospital chart before roentgen arteriography was performed. Twenty-four underwent x-ray

![Doppler focusing probe placed on center of eyelid for focusing through the eye to the posterior orbital vessels. It is constructed with dual crystals: the transistor is activated by 4 volts p-p 5 MHz energy. Focusing is accomplished by means of a concave plastic lens.](http://stroke.ahajournals.org/)

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arteriograms after the carotid Doppler survey. Results from the first 24 radioangiography patients were surveyed prior to x-ray, as listed in table 1. Forty-four carotid bifurcations of the 48 sides were compared angiographically. Four sides were not studied by x-ray. Table 2 summarizes the comparisons.

### Table 1

**Comparison of Doppler Ultrasonic and X-ray Angiography**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age, sex</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>E</td>
</tr>
<tr>
<td>1. M.D.</td>
<td>54 F</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>2. E.O.</td>
<td>55 M</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>3. R.F.</td>
<td>58 M</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>4. G.C.</td>
<td>70 F</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>5. G.S.</td>
<td>59 M</td>
<td>N</td>
<td>S</td>
</tr>
<tr>
<td>6. P.E.</td>
<td>14 M</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>7. D.S.</td>
<td>79 M</td>
<td>N</td>
<td>NV</td>
</tr>
<tr>
<td>8. W.H.</td>
<td>11 F</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>9. A.B.</td>
<td>49 M</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>10. C.T.</td>
<td>62 M</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>11. G.B.</td>
<td>70 M</td>
<td>N</td>
<td>NV</td>
</tr>
<tr>
<td>13. P.A.</td>
<td>63 M</td>
<td>DcC</td>
<td>N</td>
</tr>
<tr>
<td>14. L.F.</td>
<td>63 M</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>15. K.B.</td>
<td>55 M</td>
<td>SC</td>
<td>N</td>
</tr>
<tr>
<td>16. W.C.</td>
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<td>N</td>
<td>NV</td>
</tr>
<tr>
<td>17. P.L.</td>
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<td>N</td>
<td>N</td>
</tr>
<tr>
<td>18. E.S.</td>
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<td>N</td>
<td>SC</td>
</tr>
<tr>
<td>19. A.S.</td>
<td>54 F</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>20. A.C.</td>
<td>64 M</td>
<td>N</td>
<td>N</td>
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<td>21. G.M.</td>
<td>71 M</td>
<td>N</td>
<td>NC</td>
</tr>
<tr>
<td>22. R.W.</td>
<td>69 M</td>
<td>Bi</td>
<td>BiN</td>
</tr>
<tr>
<td>23. C.S.</td>
<td>54 M</td>
<td>N</td>
<td>S</td>
</tr>
</tbody>
</table>

C = common carotid artery; E = external carotid; I = internal; O = ophthalmic; V = vertebral; N = normal diameter or flow; S = stenosed, and decimal ratio of diameter decrease; O = occluded; NV = nonvisualized; NS = normal but small diameter; K = kink; C = calcified; PL = plaque; Bi = biphasic; RV = reversed flow; Dc = decreased flow; — = undecided or not attempted; Col = collateral fill; S.3 = fractional decrease in lumen.

The first line for each patient represents Doppler findings, and the second line represents x-ray findings.

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TABLE 2

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>E</th>
<th>I</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agree Normal</td>
<td>40</td>
<td>31</td>
<td>29</td>
<td>100</td>
</tr>
<tr>
<td>Stenosis 50%</td>
<td>39</td>
<td>30</td>
<td>20</td>
<td>89</td>
</tr>
<tr>
<td>Disagree</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Nonvisualized ultrasonic</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
<td>37</td>
<td>41</td>
<td>119</td>
</tr>
</tbody>
</table>

See footnote to table 1 for explanation of the abbreviations.

Results

NORMAL CAROTID BIFURCATION

Figure 3 illustrates day-to-day reproducibility of the normal Doppler flow images from a 30-year-old male volunteer. The internal carotid visualizes consistently in normal volunteers, but frequent difficulty was experienced in visualizing the external carotid, as illustrated. The external carotid visualizes in front of the mandibular angle. As it courses in a more superior direction, it frequently turns posteriorly and crosses over the internal carotid just below the angle of the jaw (fig. 3). A clearly visualizing bifurcation leaves no doubt as to which branch is represented. There are several characteristics of the internal flow image which aid in its identification when the external does not visualize. It usually can be traced further headward and in a direction posterior to the mandibular angle in the notch between the jaw and the mastoid process. Another difference between the normal internal and the normal external is that the internal has a more continuously moving character of the Doppler shifted audio signal throughout the heart cycle, and it is less pulsatile than the external signal.

Distally the normal internal carotid occasionally takes a deeper course. The Doppler audio frequency increases because the angle of the sonic beam with the flow stream becomes smaller. At the bifurcation the flow velocity often increases as the beam enters both the external and the internal carotids, producing an increase in Doppler audio frequency. The character of the common carotid signal is a summation of the external and the internal signals.

Among the 24 patients x-rayed, 11 normal bifurcations were confirmed by both angiographical methods. Ultrasonic angiograms of the two youngest patients, No. 8 and No. 12, are shown in figure 4. (Both sides in each patient were considered normal by Doppler survey, and the right bifurcation of each was normal by x-ray angiography.) These normal patient studies demonstrate that an exact reproduction of the x-ray angiogram cannot be expected of the ultrasonic image. The Doppler views the carotids with an ultrasonic beam tilted to a 60° angle with a sagittal

![Figure 3](image-url)

Doppler ultrasonic angiograms repeated on three different days on the same normal subject. The right common and its internal carotid branch are always traced to the mandibular-mastoid notch. The more anteriorly placed external carotid is less easily traced, but may be traced cephalad until it crosses the internal branch.
plane while the x-ray beam views the blood vessels with a 90° angle with the body axis. In addition, the present manual ultrasonic scanning allows slight movements of the patient during the 30 minutes presently required to produce a complete image.

Patient No. 8, hospitalized because of "blacking out spells," produced Doppler bifurcation images clearly separating internal from external carotid arteries on both sides. Ophthalmic flow signals were present and in the normal anterior direction, but of especially high amplitude on the left side. By x-ray the right bifurcation was confirmed as normal; the left was not x-rayed, but the left internal carotid between the ophthalmic artery origin and the circle of Willis proved to be narrow with the left anterior cerebral filling from the right. The case illustrates the ability of the cervical Doppler angiography to recognize the normal carotid arteries and to evaluate the functional patency of the internals to the level of the ophthalmic arteries when used in conjunction with retrobulbar flow detection.

Patient No. 12 also illustrates the ability of the carotid angiography to identify ophthalmic flow signals in normal internal circulation even when the external fails to visualize. In addition, this patient demonstrates the ability of the focusing probe to detect vertebral artery flow. By x-ray this patient demonstrated a normal right bifurcation and large vertebral arteries. She had a highly vascular area in the right occipital lobe. The nonvisualizing external carotids were concluded to be normal on the basis of auxiliary nonimaging signs of palpable facial pulses.

**CAROTID STENOSIS AND PLAQUES**

Among the first 60 consecutive patients imaged with the Doppler ultrasound, 41 calcified lesions have been diagnosed in the lateral carotid walls. These have all been represented by interruptions in the continuity of the sound and image of the arterial blood flow. Ten calcified lesions were found below or at the bifurcation, nine at the origin of the external, and 22 at or just above the origin of the internal. In addition, eight carotid arteries displayed a curious inverted flow signal. This, as yet unexplained, phenomenon occurred only once among the normal volunteers. It may be due to scattered calcium granules or other abnormal vessel wall deposits. It has been frequently found in patients with transient ischemic attacks. Patient No. 2 illustrated ultrasonic detection of calcified plaques. It was our first experience with a nonvisualizing segment in an otherwise uninterrupted bifurcation image and was incorrectly diagnosed as stenosis. The radiologist, however, felt there was an abnormal slowing of blood flow in the right internal.

Patient No. 23 illustrates the usefulness of the ultrasonic Doppler angiography in diagnosing both stenosis and calcified plaques without stenosis. He had a history of left amaurosis fugax which began three weeks earlier. Ophthalmodynamometry revealed a decreased left retinal arterial pressure. Bilateral carotid flow imaging (fig. 5) revealed bands of nonimaging across the flow channels. On the left the Doppler audio signal disclosed a sudden increase in frequency within the stenosed segment and a turbulent sound downstream beyond the stenosis. The stenosis was accompanied by a reversal of the left ophthalmic flow. The sonically opaque bands extending across both bifurcations where no flow signal was detected were interpreted to be calcium deposits in the lateral aspect of the arterial walls. X-ray angiograms (fig. 5) revealed a high-grade stenosis in the left internal carotid where the high frequency in the Doppler signal occurred. Surgical exposure and endarterectomy on the left revealed a hard calcium deposit in an extensive fatty plaque extending from the bifurcation into the severely stenosed internal.

Patient No. 23 demonstrates the full range of findings accompanying a discrete stenosis which produces a sharp increase in frequency accompanied by downstream turbulent flow signals. The reversal of flow in the homolateral ophthalmic proved that collateral circulation was insufficient to support in-
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tracranial arterial pressure on the side of the lesion. This patient’s findings also demonstrate sensitivity of ultrasound to calcium deposits in atherosclerotic plaques.

OPHTHALMIC FLOW SIGNALS

A reversal in the ophthalmic flow signal has been invariably associated with stenosis or obstruction of the homolateral internal carotid (table 2). We obtained 41 ophthalmic flow signals in patients also x-rayed. Eight ophthalmic signals which were reversed were all associated with a stenosis greater than 50% of the homolateral internal carotid. There were, however, six out of 14 stenosed internals whose ophthalmic flows were in the normal anterior direction. Two of these may be explained by concomitant stenosis of the homolateral external carotid. In the remaining four, collateral circulation was demonstrated from the contralateral carotid through the circle or through the internal maxillary.

Patient No. 41 (fig. 6) illustrates the interpretation of the Doppler angiogram when internals poorly visualize but ophthalmic flow is normal. She was 54 years old with a previous diagnosis of temporal arteritis. She had headaches over that artery and a buzz in her right ear. Momentary occlusion of the right common carotid caused no problems. Ultrasonic flow imaging disclosed nonvisualizing internal carotid arteries with well-visualized common and external channels. The ophthalmic signals in the posterior orbit were present in the normal anterior direction but slightly weaker on the left. The Doppler angiogram was interpreted as “severe bilateral carotid disease but with as yet normal ophthalmic flow.” X-ray angiograms disclosed an occluded left internal and a stenosis of the right intracranial internal but with crossfill from the right and strong collateral circula-

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FIGURE 5

Left and right ultrasonic angiograms (center panels) of Patient No. 23 illustrating calcified plaques across both bifurcations between “a” and “p.” A severe stenosis also is seen in the left (upper) internal carotid on both ultrasonic and roentgen angiograms (left panels). The right panels illustrate the Doppler analogue flow wave forms with zero flow reference lines drawn in. Lower right panel illustrates, from above downward, normal right common, external, internal and ophthalmic (posterior orbital) wave forms. The upper right panel discloses, from above downward, the left common systolic flow only, normal external, internal carotid, low, mid (in stenosis), high (above stenosis), and ophthalmic (reversed) flow wave forms. Stenosis of the left internal is shown on both Doppler and x-ray arteriograms.

FIGURE 6

Left and right (center panels) ultrasonic angiograms of Patient No. 41 showing stump of occluded internal and well-visualized external. Lower center panel shows poorly visualized takeoff of right internal. Roentgen angiograms are shown in left panels. Lower traces of both right and left show normal anterior-flowing ophthalmic signals. Collateral circulation through right vertebral and right external maxillary were demonstrated by other x-ray angiograms.
tion from the left internal maxillary and right vertebral arteries. Exploratory surgery of the left bifurcation revealed no sign of arteriosclerosis, but did reveal an organized thrombus in the left internal. It was removed but without back bleeding. A biopsy report indicated a nonspecific arteritis. This patient illustrates that the normally directed ophthalmic signal indicates a normal pressure gradient from the intracranial carotid but does not prove the internal open. The Doppler angiogram of this patient also illustrates the frequent finding of a greater than usual length of the external image where there is severe stenosis of the ipsilateral internal.

**X-RAY VERSUS ULTRASONIC ARTERIOGRAPHY**

Table 1 compares results of x-ray angiography with ultrasonic angiography among 23 patients undergoing both tests. Table 2 summarizes the agreements and disagreements between the two tests. Out of the 119 vessels compared by both techniques there were 12 disagreements. On only six out of 86 occasions did the ultrasonic technique falsely diagnose stenosis. We defined a false positive when the Doppler survey indicated greater than 50% narrowing in an artery, but the x-ray did not show 50% or greater obstruction. The first false positive occurred in Patient No. 2 previously discussed. A hiatus in the continuity of the internal carotid flow channel was caused by a complete lack of flow signal and was wrongly interpreted to represent stenosis. Subsequent experience at surgery with Patient No. 23 proved this phenomenon to represent localized calcification in the arterial wall.

Two of the four false positives (Patients No. 11 and No. 19) resulted from an increase in frequency beginning 3 to 4 cm above the bifurcation. Two significant anatomical situations may occur at this point accounting for an increase in frequency. Near the angle of the jaw the internal carotid may take a deeper course, changing the angle of incidence of the sonic beam. This produces a greater Doppler shifted frequency simulating the increase in velocity caused by a stenosis. Increase in frequency also occurs when the external crosses the internal in the lateral projection. The crossing of the left external and internal (Patient No. 19) and of the left internal (Patient No. 11) led to a false conclusion of stenosis. In both of the false positive patients a normal anterior flowing ophthalmic signal prevented an interpretation of impaired internal circulation. Caution in interpretation of changes in frequency at the upper end of the internal image has eliminated these phenomena as a cause of false positives.

The fourth, fifth, and sixth false positives occurred in the right external and both internal arteries of Patient No. 37. X-ray did not confirm these findings but did demonstrate severe plaquing at both bifurcations and ulceration on the left. Ophthalmic signals were in the normal direction and normal cerebral circulation was concluded. Local velocities around the plaques possibly accounted for the high Doppler frequencies. These six represent a 7% false positive rate.

We define false negatives when the Doppler scan shows no functional disease, but x-ray finds anatomical disease (narrowing greater than 50%). One false negative map was recognized in Patient No. 17 in whom x-ray angiography was interpreted as occlusion of the left internal, severe narrowing of the left external, and 85% stenosis of the origin of the right internal. Doppler arteriography did correctly diagnose the right internal stenosis but disagreed with the x-ray by visualizing a good localized common internal flow. In fact, reevaluation of the x-ray films proved the left internal to be open although narrow. Postoperative Doppler arteriography after carotid endarterectomy showed an open left internal and demonstrated great improvement on the right.

An apparent disagreement concerning the common carotid occurred in Patient No. 54 in whom the carotid ultrasonic signal and image were not confirmed by x-ray. We believe both imaging systems to be correct in that the left common was occluded at its origin as demonstrated on the aortic arch study, but that collateral flow, visualized ultrasonically in the neck, could not be seen by the x-ray angiograph.

Disagreements on the state of the external carotid were found in Patients No. 6, No. 19 and No. 37. Patients No. 19 and No. 37 represent false positives for the ultrasonic method and have since been avoided by routine palpation of the mandibular and temporal pulses. In Patient No. 6 we believe both the physiological aspect of the ultrasonic mapping and the anatomical finding of the x-ray to be correct. The apparent disagreement illustrates the inherent difference in what the two tests measure.

**Discussion**

The unique advantage of our Doppler cerebral circulation survey is its combination of all the best known techniques of ophthalmic and vertebral flow detection with a highly localizing bifurcation flow image which separates the internal from the external carotid flow and pinpoints the locus of stenosis and atherosclerotic plaques. Important features which combine to improve the overall effectiveness of this technique include the directionality of our continuous-wave flowmeter and its artifact rejection abilities as well as the compatibility of the mapping procedure with simultaneous analogue tracings and magnetic tape recordings for audio playback. All of these instrumentation advantages, when combined with physiological expertise in their interpretation, make the system an extremely powerful one in screening for cervical causes of cerebral circulation impairment. The multiple diameter measurements provide a measurement of blood flow stream diameter and the degree of stenosis. These diameter measurements make an important
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Step forward in the eventual development of a quantitative volumetric transcutaneous blood flow method.

INTERNAL CAROTID STENOSIS

The carotid Doppler survey furnishes its most definitive findings of internal carotid obstruction when a narrow segment of the ultrasonic image is accompanied by a very great increase in frequency within the segment, followed by a turbulent quality to the flow signal in the channel visualized beyond and a reversed ophthalmic artery signal in the posterior orbit. A nonvisualizing internal carotid, when the common and external are open, is also a serious finding and can only lead to a conclusion of occlusion of the internal.

OPHTHALMIC AND VERTEBRAL SIGNALS

Interpretation of the direction of flow in the ophthalmic artery should take into account that the direction is primarily related to the pressured gradient between the intracranial and extracranial circulation; this gradient may be normal, maintaining ophthalmic flow from the intracranial arteries. The finding, however, of a reversed retro-orbital ophthalmic flow signal is proof of a reversed gradient due to a lower intracranial arterial pressure on the ipsilateral side. Together with reduced flow, calcium deposits or absence of the internal carotid image indicates a diagnosis of internal carotid circulatory impairment. Operating room use of the ophthalmic flow direction may prove useful in testing for intracranial collateral circulation.

The presence of a vertebral artery signal flow is a good sign, but its absence has little significance. The effort of listening for the vertebral flows is worthwhile to complete the four-vessel study of the cerebral circulation.

CALCIFIED PLAQUES

Ultrasound appears more sensitive than x-ray in detection of calcium in the walls of the carotid arteries. On some occasions careful search of the x-ray films confirmed calcium deposits. Confirmation at surgery occurred frequently. Many patients referred for cerebral or vision symptoms were found to have calcification in the origin of the internal at the bifurcation. This finding sometimes enhanced the indications for x-ray arteriography. The finding of calcification at the bifurcation without reduced flow, if in patients with transient ischemic attacks, suggests an ulcerated atherosclerotic plaque as the source of embolism and may indicate treatment with anticoagulants or further studies by brain scan or x-ray angiography.

ANGIOGRAPHY COMPARISONS

Most of the differences between the carotid Doppler angiography and x-ray angiography arise because of the inherently different types of information that the two imaging techniques provide. While the x-ray angiogram is primarily an anatomical visualization, the Doppler flow imaging is primarily functional. Each, however, has an overlapping role to play which provides a more complete evaluation of cerebral circulation.

When x-ray demonstrates a discrete stenosis and ultrasound indicates a normal flow, we believe the stenosis is not of functional significance. X-ray does not provide the final judgment of the accuracy of ultrasonic examination. Kartchner et al.18 have shown contrast radiography to produce 10% false positives when compared to intraoperative blood flow determination. We anticipate accurate transcutaneous volumetric blood flow methods will evolve from the Doppler method of ultrasonic angiography. For the present we confine ourselves to an opinion of excellent, average or low volumetric flow based on the diameter and frequencies detected.

Present Doppler angiography and other noninvasive tests such as auscultation, palpation, thermography, ophthalmodynamometry and photoplethysmography19 will not eliminate the need for x-ray angiography. They do, however, replace it in some cases and in others indicate it, when the risk would not otherwise be taken. Normal bifurcations visualized ultrasonically may reduce the indications for x-ray angiography. On the other hand, findings of stenosis or extensive plaquing may indicate further studies by x-ray when the risks of it might not otherwise be taken.

LIMITATIONS OF THE PRESENT SURVEY

This technique and all other noninvasive methods for evaluating carotid circulation presently known reach only as far as evaluating the integrity of the internal carotid to its ophthalmic branch. A lesion beyond the ophthalmic branch of the internal such as a supracranial stenosis of the internal carotids or other concomitant intracranial disease, such as meningioma in patient No. 11, must be kept in mind, even when clear findings of carotid artery disease are found. It is because of these possibilities that most patients should undergo contrast radiography before surgery. The present detail and speed of performance of the Doppler angiography must be improved to provide more accuracy and rapid screening in stroke-prone populations.

INDICATIONS FOR CAROTID DOPPLER ANGIOGRAPHY

Indications for this test include cervical bruits, sudden developments of visual symptoms or lateralizing weaknesses, blackouts and speech changes, previous strokes, and medical or surgical follow-up. Secondary indicating factors include age over 60, known peripheral vascular or coronary artery disease, and progressive senility behavior. It is felt that the technique and its further developments will provide, when widely applied, new information to reduce the incidence of stroke.
Acknowledgments
We gratefully acknowledge the fine scanning of patients by Gail Glassen.

References
Cervical Carotid Imaging With a Continuous-Wave Doppler Flowmeter
MERRILL P. SPENCER, JOHN M. REID, DONALD L. DAVIS and PAUL S. PAULSON

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